ARMY RESEARCH LABORATORY

Summer Research Technical Report

by Jason Seik

ARL-TN-0565 September 2013

NOTICES

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Army Research Laboratory
White Sands Missile Range, NM 88002-5501

ARL-TN-0565 **September 2013**

Summer Research Technical Report

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The University of New Mexico

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2013	Final	17 June – 15 August 2013

4. TITLE AND SUBTITLE Summer Research Technical Report	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Jason G. Seik*	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Computational and Information Sciences Directorate Battlefield Environment Division (ATTN: RDRL-CIE-M) White Sands Missile Range, NM 88002-5501	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TN-0565
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

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14. ABSTRACT

Weather can have severe impacts on military personnel and the outcomes of military operations. The “My Weather Impacts Decision Aid” (MyWIDA) is being developed to determine the impact of severe weather on military operations, which requires a set of rules to reference when determining impact severity. Currently, it has only two trigger points for determining severe weather’s impact on military operations. An extrapolated curve based on empirical data that could be used to give more discrete trigger points is being researched. This would allow for more accuracy when determining the impact severity of weather on military operations. Currently, the curve is estimated to be linear but further studies are required before that assumption can be finalized.
A program is being developed to weigh all parameters, so that the user can select which ones are more important. This program is referred to as the Impact Magnitude Gradation Scheme (IMGS) and is also intended to use the extrapolated curve and compare data sets with one another—so that the user can easily establish which military force has a greater combat advantage based on current and forecast weather. Initial runs of the program show promise, but more research is required before release for official use.

15. SUBJECT TERMS

quantitative weather impacts, magnitude, parameterization

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Richard J. Szymber
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (*Include area code*)
Unclassified	Unclassified	Unclassified	UU	18	575-678-0634

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

I would like to acknowledge and thank Mr. Richard Szymber for the opportunity to work with him as a summer intern, also thanks to Mr. Terry Jameson for introducing me to the U.S. Army Research Laboratory (ARL). I would also like to acknowledge all of the researchers at ARL, White Sands Missile Range (WSMR), NM, for their help and advice during my internship.

Student Biography

I am currently a senior at the University of New Mexico working towards a bachelor's degree in Nuclear Engineering. Before being accepted as an intern at ARL, I did some minor work study tasks with some of my professors that mainly involved programming in MATLAB* and measuring the effects of radiation on ozone. In my next two semesters before graduating, I plan to research graduate school opportunities; currently, I am considering Nuclear Engineering, Nuclear Science, Mathematics, Physics, or Geology. While attending graduate school, I would like to return to ARL every summer as an intern and work my way into the WSMR Nuclear Effects Directorate.

* MATLAB is a registered trademark of The MathWorks, Inc.

1. Introduction and Background

For many years programs have been utilized to estimate the impacts of weather on military operations. The program currently being tested, "My Weather Impacts Decision Aid" (MyWIDA) uses a database of rules that it references to determine if the weather is, in effect, unsafe for operation. Within each rule there may be a set of different parameters referenced, and for each parameter there are, at most, only two critical values that the program will utilize. This means that no matter how close a value gets to the critical value, the program will treat everything as "safe" until the measured value reaches or exceeds the critical value. Part of the research is being done to extrapolate a curve based on the given critical values, as well as empirical data or mathematical proof, so that a more detailed picture of what is going on can be acquired and a better-educated decision can be made on how to proceed with any given military operation.

Another part of the research focuses on building a program to compare the data received from a military attack operation to the data received from a military defense operation. With this program, the commander can make a quick assessment on which force has the greater combat advantage based on the impacts of the local weather. The program also allows the user to adjust how important any specific weather parameter is to an operation, and thus have its impact on the final data increased or decreased.

When working with any given set of data, the entire physical area in question is broken up into many grid cells. The entire set of grid cells is often referred to as a grid cell overlay. This grid cell overlay is translucent and lies directly over a map of the region being analyzed. It is color-coded to depict the various levels of impact severity from the weather. Currently, the colors are green for no impact, amber for a moderate impact, and red for a severe impact. The amber and red correspond to the two critical values that each parameter currently has. When the extrapolated curve is applied to the data, a range of ten colors will be utilized to depict the severity of weather in a given area of interest.

2. Experiment and Calculations

The program being designed is referred to as the Impact Magnitude Gradation Scheme (IMGS) (*1*). Its main purposes are to give an extrapolated curve based on two critical values and the weather parameter in question, allow users to weigh each parameter to their own preference, and compare data sets with each other.

By default, all parameters are set to an equal weighting. If the user chooses, he or she may change the weighting factor of any parameter to light, moderate, or heavy. As the names imply, the light-weighting factor gives only a slight impact to the parameter, the moderate-weighting factor gives the parameter a sizable impact, and the heavy-weighting factor greatly increases the impact of the parameter on the final data. Currently, the moderate-weighting factor is achieved with the equation

$$P_m = \frac{1}{N} \ , \tag{1}$$

where P_m is the weighting factor (or the percentage each moderate parameter will be multiplied by), and N is the total number of parameters.

The light-weighting factor is taken as one-half of this value. The heavy-weighting factor is then found by solving the equation

$$1.0 = P_m N_m + P_l N_l + P_h N_h \ , \tag{2}$$

where N_m, N_l, and N_h are the number of moderately, lightly, and heavily weighted parameters, respectively; and P_m, P_l, and P_h are the weighting factors of the moderately, lightly, and heavily weighted parameters.

Plugging equation 1 into equation 2 and solving for P_h gives the equation

$$P_h = 1 - \frac{2P_m + P_l}{2N} \ . \tag{3}$$

An issue was discovered, however, when there are lightly weighted parameters but no heavily weighted parameters. This can be seen by manipulating equation 2 by using simple algebra and the definitions already established:

$$1 = P_m N_m + \frac{P_m}{2}(N - N_m) + 0 \ , \tag{4}$$

$$1 = \frac{N_m}{N} + \frac{1}{2} - \frac{N_m}{2N} \ , \tag{5}$$

$$\frac{N_m}{N} = 1 \ . \tag{6}$$

Equation 6 presents an obvious issue if the number of moderate parameters is not equal to the total number of parameters; therefore, it was decided that equation 7 would be used instead to determine the effects of each weighting factor:

$$1 = \frac{W_l N_l}{N_T} + \frac{W_m N_m}{N_T} + \frac{W_h N_h}{N_T}\ , \tag{7}$$

where

$$N_T = W_l N_l + W_m N_m + W_h N_h\ , \tag{8}$$

and W_l, W_m, and W_h are the light-, moderate-, and heavy-weighting factors, respectively.

These are chosen by default as one, two, and three, but they can be anything that appropriately fits the user's needs.

Once each parameter has been weighted to user satisfaction the program can be run and a curve fit will be applied to each parameter, given the two critical values provided by the user. The original idea was to apply a logistics curve to the data. Logistic curves are depicted in many phenomena including biology, chemistry, and statistics, to name a few (*2*). Since it can be difficult and time consuming to get impact data in the very high and very low ends of the curve, a simple linear relationship was assumed.

To determine the accuracy of this assumption, the two most prominent parameters were analyzed—temperature and wind speed. All other parameters, while important, simply do not show up in any significant numbers when compared to temperature and wind speed (*3*).

The impact wind speed has on any object can be thought of as the force applied by the wind and the stress levels of said object. The stress on any object is then defined as the force applied over a cross-sectional area, or

$$\sigma = F/A\ , \tag{9}$$

where strain, ϵ, is defined as the physical deformations of an object under stress.

All known solids have a basic stress/strain curve, such as the one shown in figure 1. The region from the origin to point two in figure 1 is known to be linear (*4*), and is the region of interest. The regions past this point are where materials start to permanently deform and never return to their intended shape, and are therefore assumed to be past any manufacturer's critical point.

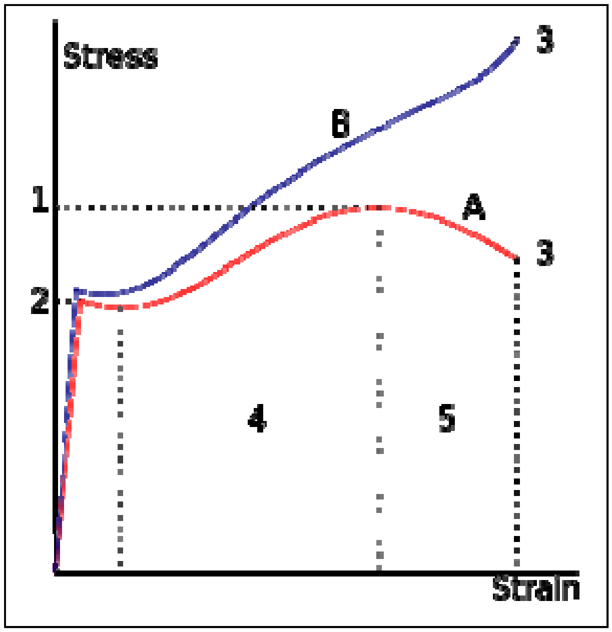

Figure 1. Simple stress vs. strain curve typical of structural steel (*5*).
Note: 1 = Ultimate Strength
2 = Yield Strength
3 = Rupture
4 = Strain hardening region
5 = Necking region
A = Apparent stress
B = Actual stress

The dynamic pressure wind speed creates can be estimated from equation 10 (*6*):

$$q = \frac{1}{2}\gamma p_s M^2 \ , \tag{10}$$

where γ is the ratio of specific heats (1.4 for air), P_s is the static pressure in Pascals, and M is the mach number of the wind, which is directly proportional to velocity.

The area that this dynamic pressure covers may be the same cross-sectional area that the stress covers, in which case the dynamic pressure equals the stress; or it may be a perpendicular area, in which the dynamic pressure is related to the stress by a factor of the ratio of the two areas:

$$\sigma = q\frac{A_q}{A_\sigma} \ , \tag{11}$$

where A_q is the area that the dynamic pressure covers and A_σ is the area that the stress covers.

In either case, this says that the strain on an object in heavy winds is directly proportional to the velocity of the wind squared, or

$$\epsilon \propto v^2 \ . \tag{12}$$

For temperature, only polymers were considered during the research. Polymers are highly durable and the military often uses various types to make their equipment. At certain high temperatures, the polymers undergo a glass-liquid transition (i.e., glass transition), in which the material drastically changes physical properties. Once this temperature has been reached, the critical point for useful operation has already passed (*7*). The only concerning effect for low temperatures is an increase in brittleness. Studies have shown that at relevant low temperatures (lowest recorded temperature on Earth was -89.2 ^{o}C [*8*]), the relationship between yield strength and temperature is mostly linear (*9*), as shown in figure 2.

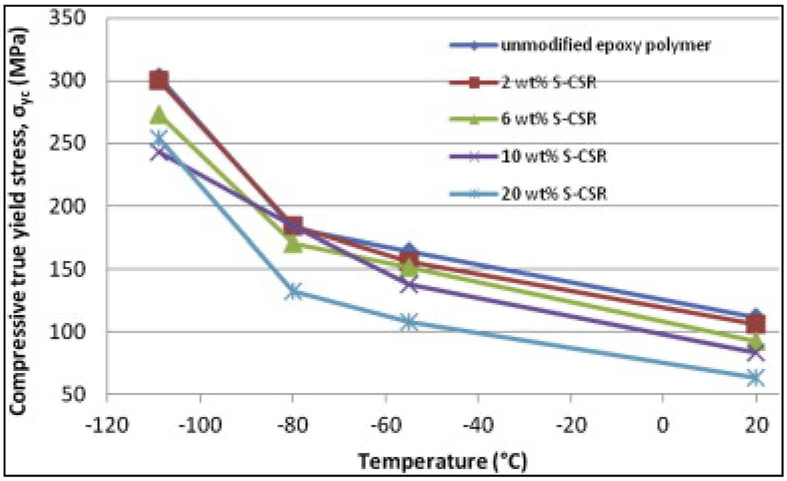

Figure 2. Compressive true yield stress of the unmodified epoxy polymer and the S-CSR particle-modified epoxy polymers vs. test temperature (*9*).

The same study also describes the relationship between storage modulus and temperature at all relevant temperatures to be mostly linear, implying that the relationship between temperature and the breaking point is also mostly linear.

The initial test data were centered on Korea and assumed that a weather system covered mostly South Korea. Five weather parameters were utilized: wind speed, temperature, cloud height ceiling, visibility, and precipitation.

The initial run was performed on the MyWIDA system, for both the attacking and defending forces. The same data was then used in the IMGS system, all with equal weighting, to show how a linear curve would affect the map overlay. The two output data were then compared to show the friendly versus threat analyses. The same process was then performed for unequal weighting. Wind speed and temperature were set to light weights, precipitation was set to a moderate weight, and cloud height ceiling and visibility were set to heavy weights. The results from the IMGS program are given in numbers; therefore, the final map overlays had to be filled in and properly aligned manually.

3. Results and Discussion

The newly implemented equation for properly weighing parameters is often the way accurate percentages are calculated. Mass percent of an element in a molecular compound is calculated in the same fashion, where the molecular weight of the element is divided by the total weight of the compound. Something as simple as a grade point average is calculated in the same fashion, but similar to a grade point average, the values assigned are slightly arbitrary. In future research we would like to assign relevant numbers for the light, moderate, and heavy weights, or possibly give the user the option to assign their own values.

For now, the linear curve continues to be used for the sake of simplicity, but research will continue in order to determine which curve is best suited. The relationship between the critical point and wind speed squared is linear. This means that in the future a new curve will need to be implemented. The relationship other parameters have with their respective critical points has not yet been well researched, but initial assumptions are that the relationships are linear. If this is the case, then the default curve will be a linear one and wind speed will have a special coding that accurately represents its relationship. If this is not the case, then each parameter may need to be programmed separately, so that each relationship can be accurately portrayed. As of now, the only confirmed linear relationship is the one between temperature and its critical point.

The resulting map overlays from both MyWIDA and the IMGS program are shown in figures 3–5. The resulting overlays from the IMGS program give much more detail than the overlays from MyWIDA. They also show a clear threat advantage for equal and unequal weighting.

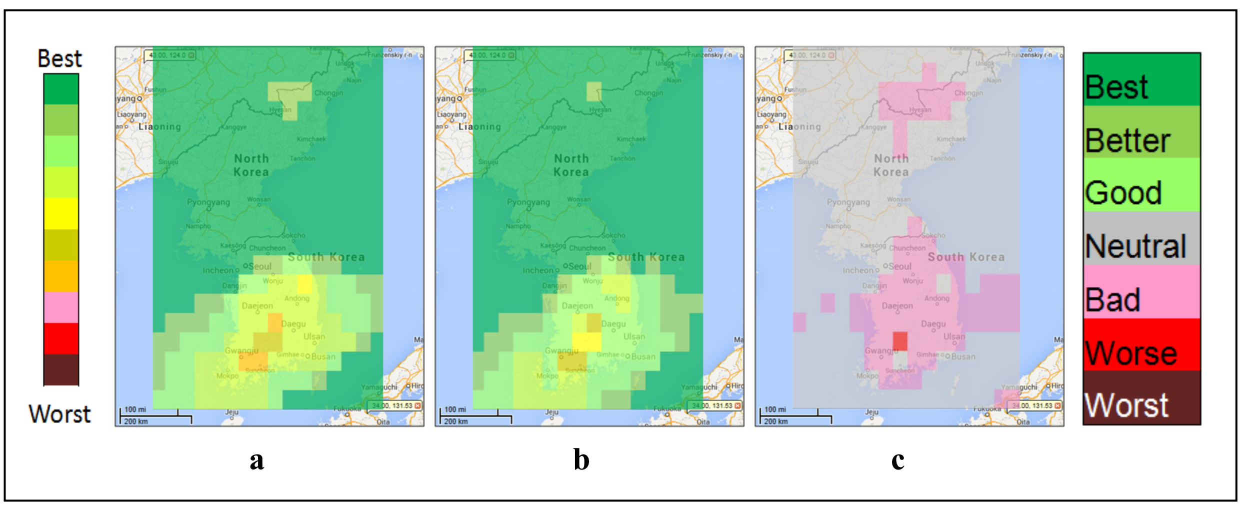

Figure 3. Equally weighted cell overlays: (a) friendly cell impact; (b) threat cell impact; (c) friendly vs. threat data analysis.

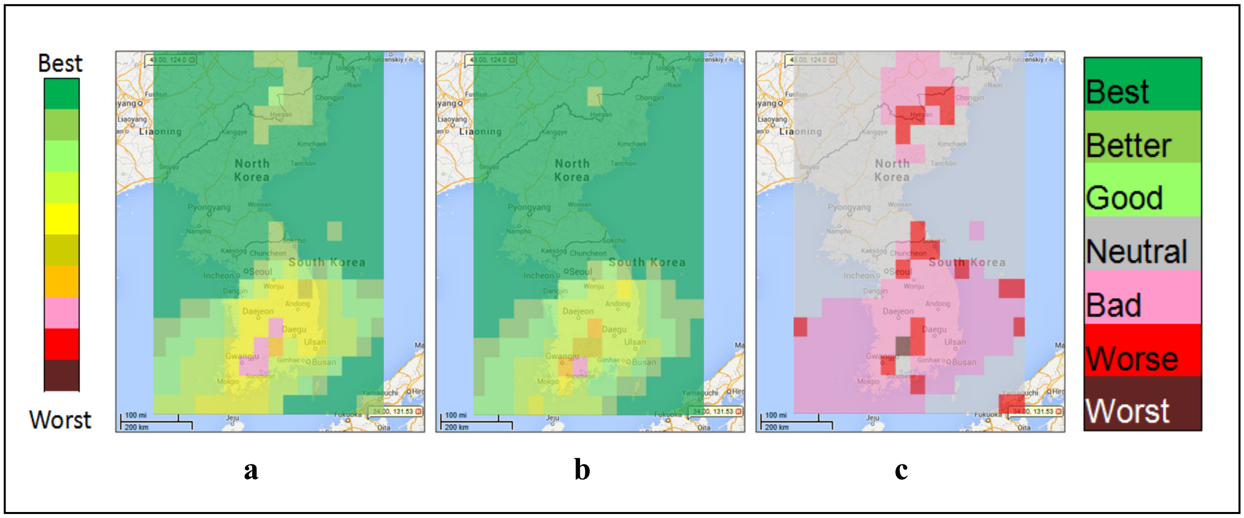

Figure 4. Unequally weighted cell overlays: (a) friendly cell impact; (b) threat cell impact; (c) friendly vs. threat data analysis.

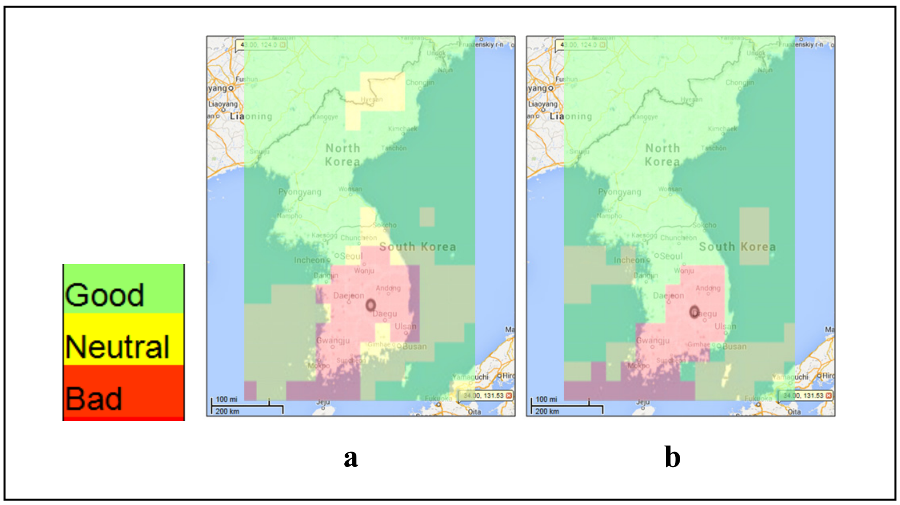

Figure 5. Original MyWIDA cell overlays: (a) friendly cell impact; (b) threat cell impact.

4. Summary and Conclusions

Much work still needs to be done before the IMGS program is finished. The assumed linear relationship between each parameter and the critical point seems to be reasonable for the time being, but for a more accurate depiction all parameters need to be thoroughly researched and analyzed. The results from wind speed and temperature are a good starting point because most rules have at least one or the other.

How each parameter is weighted has been improved, but is still slightly arbitrary at certain points. More research is highly recommended for this in the future.

The results from the Korean example are great stepping stones in moving forward and prove the concept is feasible and capable of clearly showing a friendly versus threat analysis. However, this should not distract us from the work that still needs to be done. Much fine-tuning of this program is required before it can be considered complete.

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